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Systematic Review

Using Eye-Tracking to Assess Dyslexia: A Systematic Review of Emerging Evidence

Eugenia I. Toki

Department of Speech and Language Therapy, University of Ioannina, 45500 Ioannina, Greece; toki@uoi.gr

Abstract: Reading is a complex skill that requires accurate word recognition, fluent decoding, and effective comprehension. Children with dyslexia often face challenges in these areas, resulting in ongoing reading difficulties. This study systematically reviews the use of eye-tracking technology to assess dyslexia, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The review identifies the specific types of eye-tracking technologies used, examines the cognitive and behavioral abilities assessed (such as reading fluency and attention), and evaluates the primary purposes of these evaluations—screening, assessment, and diagnosis. This study explores key questions, including how eye-tracking outcomes guide intervention strategies and influence educational practices, and assesses the practicality and time efficiency of these evaluations in real-world settings. Furthermore, it considers whether eye-tracking provides a holistic developmental profile or a targeted analysis of specific skills and evaluates the generalizability of eye-tracking results across diverse populations. Gaps in the literature are highlighted, with recommendations proposed to improve eye-tracking's precision and applicability for early dyslexia intervention. The findings underscore the potential of eye-tracking to enhance diagnostic accuracy through metrics such as fixation counts, saccadic patterns, and processing speed, key indicators that distinguish dyslexic from typical reading behaviors. Additionally, studies show that integrating machine learning with eye-tracking data can enhance classification accuracy, suggesting promising applications for scalable, early dyslexia screening in educational settings. This review provides new insights into the value of eye-tracking technology in identifying dyslexia, emphasizing the need for further research to refine these methods and support their adoption in classrooms and clinics.

Keywords: dyslexia; eye-tracking technology; reading skills; decoding; reading comprehension; visual processing; diagnostic tools; reading patterns; specific learning disorder; systematic review

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1. Introduction

1.1. Rationale

1.1.1. Reading

Reading is a fundamental skill that involves decoding symbols and extracting meaning from text via complicated cognitive activities using various reading strategies [1,2]. These include the direct (lexical) route, where words are recognized as whole units by sight, and the indirect (phonological) route, which involves decoding words by translating letters into sounds. Together, these routes enable readers to engage effectively with text [3]. Reading allows individuals to comprehend written language and communicate via written forms. To effectively connect with a text, it is important to understand and derive meaning from the words. Upon recognizing the words, the reader actively engages with the text, extracting, evaluating, and internalizing information [1]. Through reading, individuals can access vast amounts of knowledge, communicate ideas, and participate in both personal and academic growth [2]. Reading eventually becomes an automatic process for many, but mastering this skill involves learning and practicing various interconnected abilities over time [4].

1.1.2. Reading Abilities

Certain abilities are necessary for effective reading and comprehension [1]. The first important ability for early readers is 'decoding', the indirect route that involves converting written letters into their corresponding sounds to build foundational reading skills [5]. 'Phonemic awareness' helps readers manipulate individual sounds in words and supports decoding [6]. As readers advance, they increasingly rely on the direct (lexical) route, recognizing familiar words by sight, which supports fluency and comprehension. Mastery of both routes is necessary for smooth and efficient reading, bridging initial decoding skills with automatic word recognition. Decoding is necessary for understanding the text. 'Vocabulary knowledge' is essential for grasping the meaning of words in context, enabling readers to comprehend a text's overall message. Strong vocabulary develops through instruction and exposure to diverse reading materials. 'Fluency' is the ability to read text with accuracy, speed, and prosody [5] relies on a balance between the phonological route for decoding unfamiliar words and the lexical route for recognizing familiar ones. Together, these routes contribute to reading comprehension, enabling readers to understand and interpret text seamlessly. This integration of both routes reflects the development from early decoding efforts to fluent, proficient reading [3]. It bridges decoding and comprehension, allowing children to focus on meaning once word recognition becomes automatic. 'Reading comprehension', the goal of reading, is the ability to understand and interpret text, connecting it to broader ideas [5]. It includes abilities like summarizing, making inferences, and analyzing critically.

Critical thinking is required to evaluate deeper meanings and distinguish fact from opinion, while background knowledge helps readers connect new information to what they already know [1]. Metacognition (self-monitoring) allows readers to recognize when they don't understand something and adjust their strategies to improve comprehension [1]. Therefore, the ability to read is not a single skill but a combination of interconnected skills that develop over time, with the indirect (phonological) route laying the groundwork for early reading and the direct (lexical) route supporting fluency and comprehension. Each route complements the other, building towards a proficient reader. Teaching reading requires attention to these multiple layers, ensuring learners recognize words and understand and engage meaningfully with the text.

Comprehending written language is a crucial aspect of communication, distinct from verbal expression and auditory perception. Reading, unlike speaking and listening, requires explicit instruction and practice. Many children find it complex [7].

1.1.3. Dyslexia

Children who struggle with specific learning areas, such as reading, writing, or mathematics, are diagnosed with a Specific Learning Disorder (SLD) [7–9]. Difficulties include (i) reading: language milestone delays, incorrect spelling, slow reading, challenges with rhymes or words sounding alike, decoding not familiar or nonsensical phrases or single words, (ii) writing: low writing skills, errors in grammar, improper punctuation, weak paragraph structure, incorrect spelling, sloppy handwriting, and (iii) mathematics: the primary issue is in arithmetic and also having trouble understanding or describing mathematical terms; having trouble with math processes or ideas; math sign decoding, making copies of numbers or figures, following math sequences, add/multiply tables [10]. Even when the child is in a typical educational setting, these issues manifest as difficulties in a particular area that do not align with the child's intellectual ability and expected level of performance [7,11]. When children struggle in a particular area even after receiving targeted treatment, it is typically determined that they have unique learning challenges [7]. SLD is a neurodevelopmental condition that affects cognitive functioning and behavior, involving genetic, epigenetic, and environmental factors impacting the brain's information processing.

A common SLD is an impairment in reading, usually referred to as Dyslexia (F81.0). Dyslexia is a word of Greek origin that comes from (i) the prefix 'δυσ-' (dys-) = poor or difficulty, and (ii) the word 'λέξις' (lexis) = word, meaning difficulty with words. Precisely, dyslexia includes "*word reading accuracy, reading rate or fluency, and reading comprehension*" [7], and is characterized by problems with word recognition, decoding, and spelling. Usually, individuals with dyslexia present deficits in various executive function (EF) domains and working memory [12]. These issues tend to increase as time goes on, and children who have difficulty reading as they grow older often experience negative educational results and limited job opportunities [9]. Developmental dyslexia is the main type of learning disorder, representing around 80% of all such problems, with a pooled global prevalence of 7.1% (95% CI: 6.3–8.0%) [9] in the pediatric population and a higher incidence in boys [13]. Upon its occurrence, it is important to specify any additional difficulties, such as reading comprehension or math reasoning challenges [7]. In educational contexts, dyslexia is often classified under ACNEAE (Students with Specific Educational Support Needs) rather than ACNEE (Students with Special Educational Needs). This classification reflects dyslexia's status as a specific learning disorder, requiring targeted interventions to support reading and language skills within mainstream educational settings [14].

Recent research suggests that the ability to focus on visual-spatial information is a powerful predictor of preschool children's future reading abilities [15]. Dyslexia identification is complex and timely, with variability of symptoms, presentations, and comorbidities, which often blur diagnostic boundaries. Traditional diagnostic methods frequently rely on subjective observations and lengthy assessments, leading to delays or inaccuracies in diagnosis. However, early detection is vital, as the developing brain's plasticity enables it to form compensation mechanisms, allowing for more effective rewiring of neural pathways involved in reading. Timely intervention, such as phonological training and decoding exercises, can take full advantage of this adaptability, helping children develop critical reading skills. This not only prevents academic setbacks but also reduces frustration, anxiety, and behavioral issues linked to undiagnosed dyslexia. By capitalizing on the brain's early flexibility, early intervention enhances long-term outcomes, including academic achievement and overall quality of life [16]. Children at risk of dyslexia face early difficulties in language, cognition, and social-emotional skills [6]. Emotional and behavioral problems often occur alongside dyslexia, with early intervention improving outcomes [17].

1.1.4. Eye-Tracking Technology

An effective approach to examining visual attention and behavior associated with developmental disorders, such as dyslexia, involves the use of eye-tracking technology [18]. Eye-tracking technology is a practical, objective, and non-invasive tool for visual perception that measures where we look. This is accomplished by utilizing sensors or cameras to monitor and record the subject's eye movements, providing crucial insights into visual attention and behavior [19,20]. During the eye-tracking process, advanced technological methods are utilized to measure the focal point of gaze accurately. This technique involves directing near-infrared light to the eyes, enabling the capture and tracking of reflections from both the pupil and the cornea. These reflections are systematically recorded and analyzed to ascertain the precise direction of visual focus, contributing to a deeper understanding of visual attention mechanisms. Key measures of eye movements, including fixations, saccades, scan paths, dwell time, and gaze duration. These measures provide insights into how information is processed, attention shifts, engagement, and cognitive load. Additionally, gaze duration can differentiate processing between different groups, for instance, typically developing children and children with dyslexia [20].

Eye-tracking can enhance accuracy in diagnostics, clinical performance, and rehabilitating accomplishments [21]. Eye-tracking technology has become a key tool for screening and diagnosing dyslexia in children. It measures fixation duration, saccadic movements, and gaze patterns during reading tasks to identify dyslexia-associated anomalies. Studies have shown that these metrics can distinguish dyslexic children from their typically developing peers, making eye-tracking a promising method for early and non-invasive dyslexia detection in schools [19,22]. In addition to identifying dyslexia-related reading patterns, eye-tracking helps clarify the use of the two main reading routes—the direct (lexical) and indirect (phonological) routes—particularly in dyslexic readers. While most readers use the direct route to quickly recognize familiar words by sight, dyslexic readers often rely more heavily on the indirect route. Eye-tracking data reveal longer fixations, frequent saccades, and increased regressions in dyslexic readers as they actively decode words sound-by-sound, especially with unfamiliar or complex words [23]. In contrast, fluent readers primarily using the lexical route show quick fixations and fewer regressions. This insight is valuable for assessing dyslexic readers and tailoring interventions to help develop automatic word recognition skills, ultimately supporting reading fluency. Current research focused on various eye-tracking applications, including comparing outcomes with traditional neuropsychological assessments, evaluating visual factors (e.g., background colors), and incorporating advanced technologies like convolutional neural networks (CNNs) for data analysis. These studies utilized different participant groups, often school-aged children, and tested various text conditions to understand the effects on dyslexic readers [22,24,25].

A consistent trend in the research shows that children with dyslexia exhibit longer fixation durations, more frequent regressions, and inefficient saccadic movements. Several studies confirmed that visual aids (e.g., modified background colors) and personalized reading interventions could positively influence dyslexic reading behaviors, suggesting that customized approaches may enhance reading fluency. Furthermore, integrating machine learning models, such as CNNs, has significantly improved the diagnostic accuracy of eye-tracking methods, demonstrating their potential for early and scalable dyslexia screening [19,22,26].

Despite the advancements, gaps persist, particularly regarding the standardization of eye-tracking protocols across studies. Many research efforts use varied methodologies and demographic groups, leading to results and diagnostic criteria inconsistencies. A holistic approach to the latest research is essential to outline the current state, trends, and gaps in eye-tracking research for dyslexia diagnostic accuracy and accessibility. This systematic review of eye-tracking technology for dyslexia detection highlights essential aspects often overlooked in existing literature. Many reviews focus on general usage but fail to compare device types (i.e., screen-based vs. mobile) and their specifications. The question about specific hardware and software helps to broaden the scope and establish more precise guidelines, addressing a recognized gap in prior reviews [27,28]. Many systematic reviews assess reading abilities and attention but often lack comprehensive categorization or linkage to specific metrics. This detailed approach to cognitive and behavioral domains, like attention and reading fluency, enhances the depth of these reviews [27]. Existing reviews highlight diagnostic capabilities but often conflate screening and assessments. The Scope and Purpose of Evaluation questions clarify these distinctions, addressing the need for consistency in eye-tracking applications across diagnostic stages [19,27]. While previous studies highlight eye-tracking as a quick diagnostic tool, they often neglect the total time needed for different components. Addressing this gap could enhance procedures in educational, clinical, technological, or other settings [27]. Further, some reviews mention holistic profiles or specific aspects, but our question focuses on whether evaluations use multimodal approaches, like combining eye-tracking with EEG or behavioral tests. Including this detail could help connect eye-tracking methods to a more comprehensive developmental assessment framework [19]. This systematic review can pave the way for more standardized and efficient diagnostic methods.

1.2. Objectives

Next follows a description of the study's research aim and questions.

1.2.1. Research Aim

This study aims to systematically review the use of eye-tracking technology for detecting dyslexia in school-aged children. It seeks to identify and categorize the types of eye-tracking technologies used, their specifications, and software platforms. The study will also evaluate the range of cognitive and behavioral abilities assessed, such as reading fluency and attention, and distinguish between different evaluation purposes, including screening, assessment, and diagnosis. Additionally, it aims to determine the time efficiency and practicality of these procedures and whether they provide a holistic developmental profile or focus on specific abilities. The review will identify gaps and propose recommendations for future research, enhancing the precision and efficiency of eye-tracking as a tool for early dyslexia intervention.

1.2.2. Research Questions

The research questions of this study are structured to explore various dimensions comprehensively, ensuring that this study captures the depth and breadth of the current research landscape, including the following questions:

1. What is the geographic distribution of current research on using eye-tracking technology to detect dyslexia?
2. In which sector do the included publications belong?
3. What specific types of eye-tracking technology are utilized?
4. Which cognitive, language, and communication abilities are assessed using eye-tracking technology?
5. What is the scope of the eye-tracking evaluation?
6. What is the primary purpose of the evaluation conducted using eye-tracking?
7. How much time is needed for the entire eye-tracking evaluation process, including preparation, calibration, active evaluation, and analysis?
8. Does the eye-tracking evaluation provide a comprehensive assessment of the child's profile, possibly by integrating multimodal assessments, or is it a targeted evaluation?
9. Do studies compare different types of eye-tracking technology or methodologies?
10. How do the outcomes of eye-tracking evaluations influence subsequent intervention strategies or educational practices?
11. Do studies consider diverse populations to assess the generalizability of eye-tracking results?

2. Materials and Methods

2.1. Overview

A systematic literature review was employed to find papers on the study's research questions. In conducting this systematic review, we noted that no formal review protocol has been established. To ensure methodological consistency and transparency, we addressed this by following standard systematic review guidelines. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement guidelines, providing essential reporting elements for conducting reviews and meta-analyses [29]. Systematic Review PRISMA 2020 Checklist is included in a Supplementary File. The following subsections explain these components in detail.

2.2. Search Strategy

This systematic review followed the PRISMA 2020 guidelines to ensure transparency and comprehensiveness in identifying studies that utilize eye-tracking technology to detect and assess dyslexia in children. The search was conducted across MEDLINE and ScienceDirect databases, focusing on studies related to developmental dyslexia, reading disorders, and disabilities in children, as well as various diagnostic approaches. We focused on studies that use eye-tracking as a primary or complementary tool regarding reading tasks involving alphabetical writing systems. In contrast, studies using non-alphabetic scripts (such as Arabic or Chinese) were excluded due to the ongoing uncertainty about whether reading processes are genuinely universal across all orthographies [30]. While some basic reading principles may apply universally, significant differences in the processes needed to master non-alphabetic systems, such as grapheme-phoneme mapping, suggest that alphabetic systems warrant specific consideration [31]. Limiting the scope to alphabetic orthographies helps ensure a more focused and coherent analysis of dyslexia detection using eye-tracking without introducing complexities from fundamentally different reading systems, such as ideographic or syllabic scripts.

Search Sources:

The following search query was applied:

(Eye Tracking) AND ((developmental dyslexia) OR (reading AND (disorder OR disability))) AND (detection OR screen OR assess OR diagnosis) AND child.

- Population: The search included terms related to dyslexia and reading difficulties, such as "developmental dyslexia", "reading disorder", and "reading disability".
- Intervention: The term "Eye Tracking" was used to capture studies that employed eye-tracking technology in the context of dyslexia detection and assessment.
- Outcome: The search strategy included terms such as "detection", "screen", "assess", and "diagnosis" to encompass studies addressing various aspects of dyslexia evaluation.
- Population Subgroup: The term "child" was included to focus on studies involving children and ensure the results were relevant to a pediatric population.

Databases Searched:

1. MEDLINE
2. ScienceDirect

Search Date:

The search was conducted from 10 August 2024 to 14 September 2024.

Inclusion Criteria:

- Studies utilizing eye-tracking technology for the detection, screening, assessment, or diagnosis of dyslexia in children.
- Studies using alphabetic scripts.
- Population limited to children (0–18 years old).
- Articles written in English.
- Peer-reviewed original research.

Exclusion Criteria:

- Studies focused on populations outside of children or unrelated disorders.
- Non-eye-tracking-based research.
- Studies using non-alphabetic scripts (such as Arabic or Chinese)
- Reviews, editorials, or non-original research.

Search Process:

1. The search query was applied to each database (MEDLINE and ScienceDirect).
2. The results were imported into the reference management tool (Zotero) for deduplication.
3. Titles and abstracts were screened by the sole reviewer (Eugenia I. Toki) following the pre-defined inclusion criteria. To mitigate potential bias, a pilot screening of [5] studies was conducted to refine the criteria. Any ambiguities were carefully documented, and expert input was sought where necessary.
4. Full-text articles were retrieved for all potentially relevant studies based on the title and abstract screening. These full texts were then thoroughly reviewed for eligibility using the predefined inclusion and exclusion criteria. Studies that did not meet the criteria (e.g., wrong population, intervention, or outcome) were excluded, and reasons for exclusion were documented. A record of the reasons for study exclusions at this stage was maintained to ensure transparency.

Search Results:

- The initial search yielded 54 articles.

- After removing duplicates, 45 unique studies were screened for eligibility.
- A total of 34 full-text articles were reviewed, of which 21 met the inclusion criteria.

Figure 1 displays the Systematic Review PRISMA 2020 Flow Diagram, which presents a visualization of the articles' selection.

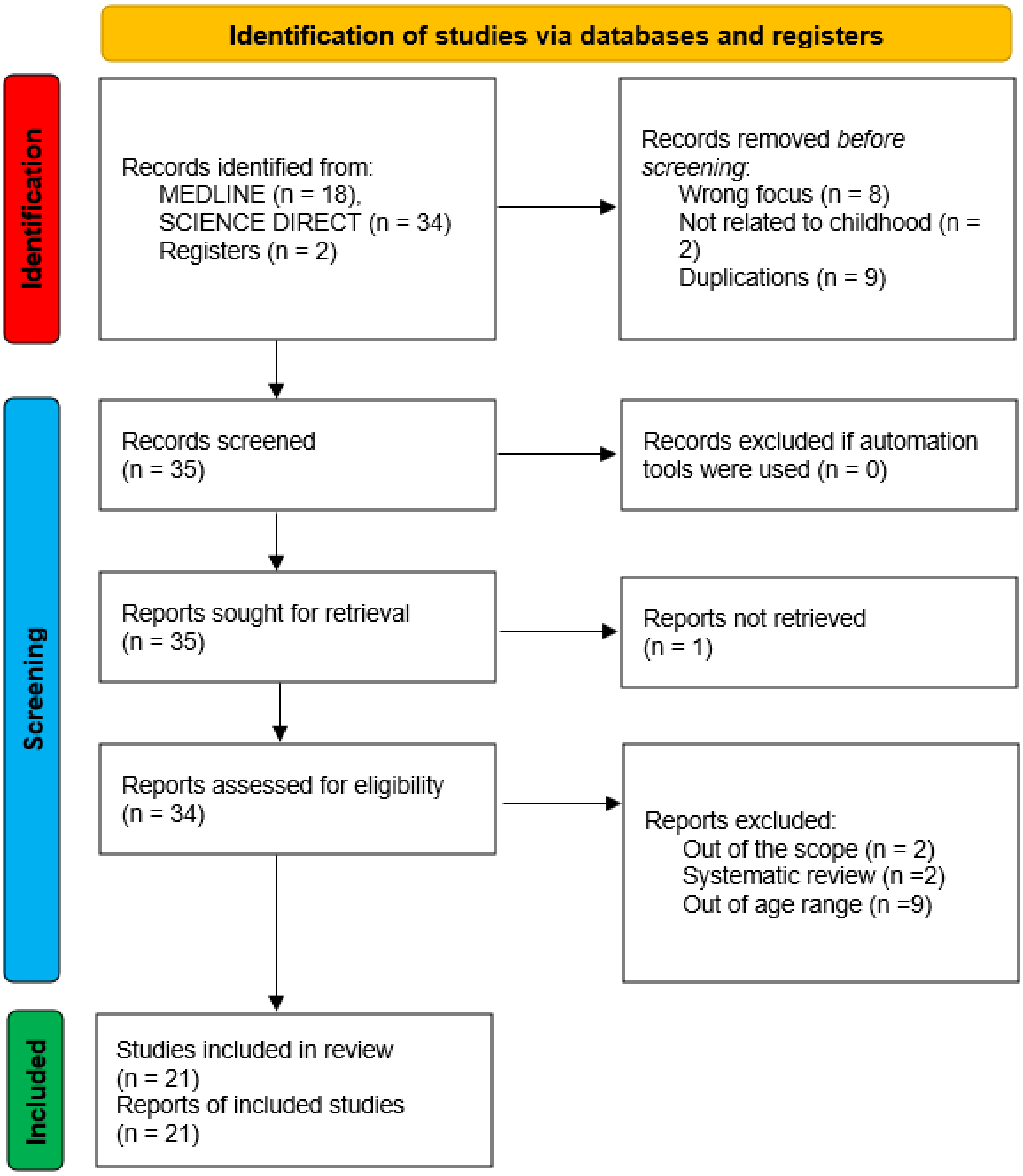

Figure 1. Systematic Review PRISMA 2020 Flow Diagram.

Example Search Queries for Each Database

MEDLINE Search Query:
(Eye Tracking[Mesh] OR Eye-tracking OR Gaze tracking) AND
((developmental dyslexia[Mesh] OR reading disorder[Mesh] OR reading disability[Mesh]) OR
(developmental dyslexia OR reading disorder OR reading disability)) AND
(detection[Mesh] OR screen[Mesh] OR assess[Mesh] OR diagnosis[Mesh]) AND

(child[Mesh] OR children OR pediatric)

ScienceDirect Search Query:

(Eye Tracking) AND ((developmental dyslexia) OR (reading AND (disorder OR disability))) AND

(detection OR screen OR assess OR diagnosis) AND child.

Search Limits

- The search was restricted to English-language studies only.
- Publication dates: 10 August–14 September 2024.
- Studies focused on children (0–18 years old).

By following PRISMA 2020 guidelines, this search strategy provides a transparent and structured approach to identifying relevant literature. It includes the key search terms, databases used, the search process, and a detailed description of inclusion and exclusion criteria, ensuring reproducibility and clarity.

2.3. Data Extraction

The data extraction form used in this systematic review is described by systematic methods to collate and synthesize findings of studies that address the study's clearly formulated research questions. Microsoft Excel was used as the primary tool for extracting data related to the characteristics of the included studies, focusing on eye-tracking technology and dyslexia detection. Initially, a pilot test with five included studies was conducted to refine the data extraction structure and ensure consistency.

The data synthesis used tables, figures, and a narrative approach to systematically present findings. The extraction process began by documenting the study's key characteristics, including the first author's surname, title, and year of publication. Additionally, the geographic distribution of each study was extracted, specifying the primary country associated with each study and the number of studies per country.

Further data extraction focused on the eye-tracking technologies used, covering both hardware and software specifications. This included details such as the type of technology (e.g., screen-based, mobile, infrared, or video-based) and its resolution, accuracy, and software platforms.

Data were also extracted for the sectoral classification, where studies were categorized into educational, clinical, or computer science and engineering sectors based on their primary focus. To understand the cognitive, language, and communication abilities assessed, data were extracted on the specific measured domains, such as attention, memory, visual processing speed, decoding, word recognition, reading fluency, comprehension, and phonological awareness.

The review sought to capture all available data regarding the scope of eye-tracking evaluations, focusing on quantitative metrics (e.g., fixation counts and reading speed) and qualitative aspects (e.g., engagement and comprehension). When studies reported results for multiple time points or analyses, all relevant outcomes were collected unless a study specifically limited reporting to certain time points. In such cases, the most comprehensive or recent data were prioritized.

Additionally, data for the purpose of evaluation (screening, assessment, diagnosis, and monitoring) were retrieved alongside information regarding the evaluation process time, including preparation, calibration, active evaluation, and analysis. The evaluation type (holistic vs. targeted) was also examined to determine the breadth of the assessment.

The extracted data also covered studies that compared different technologies and methodologies and how these comparisons influenced subsequent interventions and educational practices. The review also focused on studies that examined population diversity, including demographic variables, to assess the generalizability of the findings across different contexts.

This systematic approach ensured that all relevant data were collected and synthesized, providing a clear and comprehensive view of the role of eye-tracking technology in dyslexia detection.

Some of the articles [32–37] meet inclusion criteria but are excluded as they are out of age range, missing age information or present other primary disorders.

3. Results

This systematic review included 21 studies. The studies included in this systematic review are chronologically displayed in Table 1.

Table 1. Studies included in this systematic review.

N: 21	Reference Article	Authors	Title	Year of Publication
1	[38]	Åsberg Johnels et al.	Face processing in school children with dyslexia: Neuropsychological and eye-tracking findings	2022
2	[39]	Pereira et al.	Effects of word length and word frequency among dyslexic, ADHD-I, and typical readers	2022
3	[40]	Vajs et al.	Spatiotemporal eye-tracking feature set for improved recognition of dyslexic reading patterns in children	2022
4	[41]	Łuniewska et al.	The effect of inter-letter spacing on reading performance and eye movements in typically reading and dyslexic children	2022
5	[42]	Parshina et al.	Global reading processes in children with high risk of dyslexia: A scanpath analysis	2022
6	[43]	Åsberg Johnels et al.	Left visual field bias during face perception aligns with individual differences in reading skills and is absent in dyslexia	2022
7	[44]	Kaisar and Chowdhury	Integrating oversampling and ensemble-based machine learning techniques for an imbalanced dataset in dyslexia screening tests	2022
8	[45]	Pereira et al.	Integrating cognitive factors and eye movement data in reading predictive models for children with dyslexia and ADHD-I	2023
9	[46]	Shalileh et al.	Identifying dyslexia in school pupils from eye movement and demographic data using artificial intelligence	2023
10	[47]	Vialatte et al.	Toward the characterization of a visual form of developmental dyslexia: Reduced visuo-attentional capacity for processing multiple stimuli made of separable features	2023
11	[48]	JothiPrabha et al.	Prediction of dyslexia severity levels from fixation and saccadic eye movement using machine learning	2023
12	[49]	Nagarajan et al.	Detection of reading impairment from eye-gaze behaviour using reinforcement learning	2023
13	[50]	Vajs et al.	Accessible dyslexia detection with real-time reading feedback through robust interpretable eye-tracking features	2023
14	[51]	Vernet et al.	The determinants of saccade targeting strategy in neurodevelopmental disorders: The influence of suboptimal reading experience	2023
15	[52]	Iaconis et al.	Ordinal pattern transition networks in eye-tracking reading signals	2023
16	[53]	Xia et al.	An interpretable English reading proficiency detection model in an online learning environment: A study based on eye movement	2024
17	[54]	Schwarz et al.	Phonological deficits in dyslexia impede lexical processing of spoken words: Linking behavioural and MEG data	2024
18	[55]	Meo et al.	Multifractal information on reading eye-tracking data	2024
19	[56]	Bilbao et al.	Eye-tracking-based characterization of fixations during reading in children with neurodevelopmental disorders	2024
20	[57]	Hokken et al.	Eyes on CVI: Eye movements unveil distinct visual search patterns in Cerebral visual impairment compared to ADHD, dyslexia, and neurotypical children	2024
21	[58]	Virlet et al.	Proprioceptive intervention improves reading performance in developmental dyslexia: An eye-tracking study	2024

To analyze this study's research questions effectively, we present a coherent flow from broad contextual information to more specific aspects of eye-tracking technology and its applications in detecting dyslexia. Next follows the analysis regarding the geographic distribution of research, sectoral classification, types of eye-tracking technologies, cognitive, language, and communication abilities assessed, scope of eye-tracking evaluations, purpose of evaluations, evaluation process time, holistic vs. targeted, comparing different technologies and methodologies, influence on intervention and educational practices, and population diversity and generalizability.

3.1. Geographic Distribution

This section focuses on the geographic distribution of the studies included in this review. Mapping the geographic spread helps to identify where research is concentrated and how it varies "across the globe". We used MS Excel to create tables and a Power-user add-in for MS Office to create the figure and the map's visualization.

Table 2 displays the primary country associated with each study in this systematic review. Further, Figure 2 presents a visualization of geographic distribution detailing the number of studies conducted in each country.

Table 2. Geographic distribution of the included studies in this systematic.

Location	Reference Study	N of Studies in Each Country [1]
Argentina	[52,55]	2
Australia	[44]	1
France	[47,51,58]	3
India	[48,49]	2
Netherlands	[57]	1
Poland	[41]	1
Portugal	[39,45]	2
Russia	[42,46]	2
Serbia	[40,50]	2
Singapore	[53]	1
Spain	[56]	1
Sweden	[38,43]	2
UK	[54]	1

[1] One principal country per study is displayed.

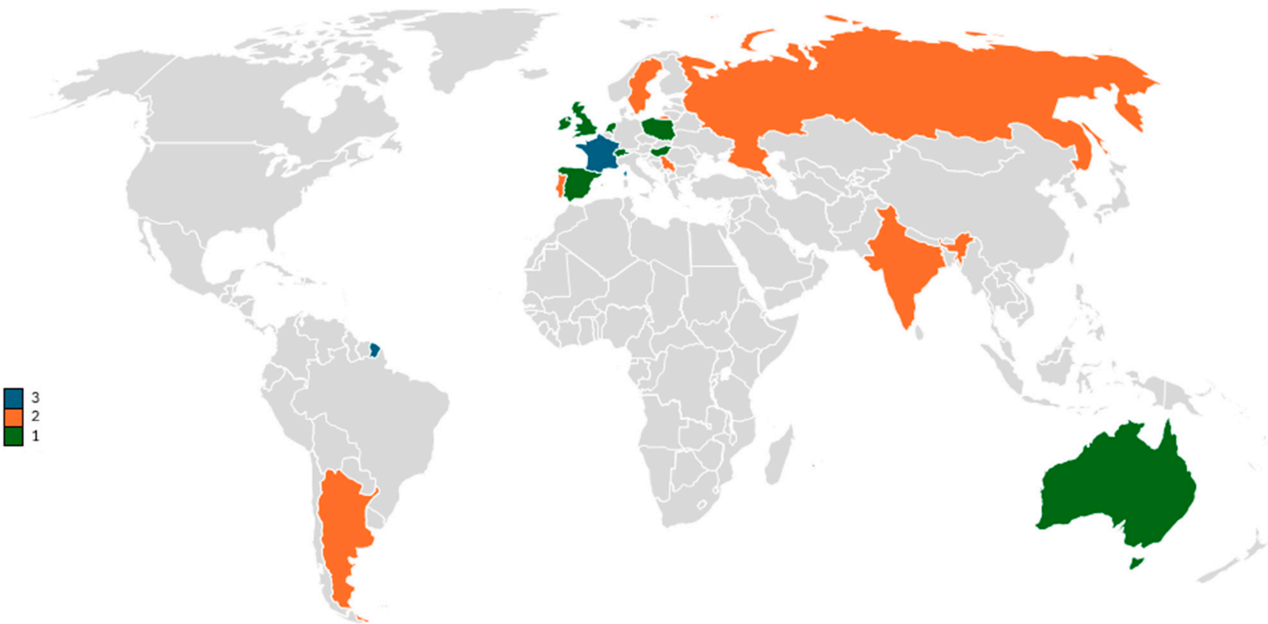

Figure 2. Visualization of geographic distribution.

The studies reviewed in this section represent a diverse geographic spread, with contributions from various countries across continents. Europe has a significant representation, with multiple studies coming from countries like France (three studies), Poland (one study), Portugal (two studies), Russia (two studies), Serbia (two studies), Spain (one study), Sweden (two studies), and the UK (one study). Beyond Europe, there are contributions from Argentina (two studies), Australia (one study), India (two studies), and Singapore (one study).

3.2. Sectoral Classification

Next, the sectors from which the publications originate are analyzed, presenting information to understand eye-tracking research's practical and academic drivers. Table 3 displays the sectoral classification of the studies included in the systematic review that fall under the educational sector (20.83%), the clinical sector (50.00%), and the computer science and engineering sector (29.17%).

Table 3. Sectoral classification of the studies included in the systematic review.

Sectors	Reference Study	(%)	N: 21
Educational	[41–43,46,53]	23.81%	5
Clinical	[38,39,45,47,50,51,54,56–58]	47.62%	10
Computer science and engineering	[40,44,48,49,52,55]	28.57%	6

3.3. Types of Eye-Tracking Technologies

This section explores the specific technologies used for understanding the practical aspects of eye-tracking in dyslexia assessment in each study. It details the hardware and software specifications associated with various dimensions of eye-tracking technology. For hardware, the types of eye trackers are categorized into screen-based versus mobile eye trackers, and infrared versus video-based options are discussed. Additionally, the accuracy and resolution levels of these devices are specified. In terms of software and analysis tools, the section identifies the specific software platforms and algorithms (e.g., for data analysis) used alongside these technologies. Table 4 details the hardware and software specifications utilized in the studies of this systematic review.

Table 4. Types of eye-tracking technologies in this systematic review.

		Hardware Specifications [1]							Software Specifications [2]	
N: 21	Reference Article	Screen-Based	Mobile	Infrared	Video-Based	Model	Resolution	Accuracy (Hz)	Platforms	Algorithms/Data Analysis
1	[38]	✓	✓	✓	✓	Tobii X2-30	-	30	iMotions: stimulus and gaze recording	Timestudio software (Version 3.19), a MATLAB-based tool, used for fixation duration analysis.
2	[39]	✓		✓	✓	SMI IVIEW X™ HI-SPEED (SensoMotoric Instruments)	0.01° tracking resolution	1250	SMI system software	Eye-tracking measures: Fixation Count (FC), Single Fixation Duration (SFD), First Pass Reading Time (FPRT), Second Pass Reading Time (SPRT), and Total Fixation Time (TFT) calculated and analyzed for the study. SPSS for statistical analysis.

Table 4. *Cont.*

		Hardware Specifications [1]							Software Specifications [2]	
N: 21	**Reference Article**	**Screen-Based**	**Mobile**	**Infrared**	**Video-Based**	**Model**	**Resolution**	**Accuracy (Hz)**	**Platforms**	**Algorithms/Data Analysis**
3	[40]	✓		✓	✓	SMI RED-m 120 Hz portable remote eye tracker		120	SMI Experiment Center software 3.7	Python environment for data processing, feature extraction, and machine learning algorithms (Logistic Regression, SVM, KNN, RF) for dyslexia classification. Statistical analysis was conducted using SPSS software.
4	[41]	✓		✓	✓	Tobii TX300	1920 × 1080	300	Tobii Studio software (version 3.4.5) was used for the experiment setup and data collection.	Fixation data (duration, number of fixations) was analyzed. Statistical analysis was conducted using mixed linear models and ANOVA approaches with MATLAB and SPSS software.
5	[42]	✓	✓	✓	✓	EyeLink or EyeLink Portable Duo	-	1000	SR Research (likely EyeLink Data Viewer)	Various mixed-effects models and scanpath analysis tools were used to assess reading behavior and patterns, available at https://osf.io/wmj4g/ (accessed on 8 November 2024).
6	[43]	✓	✓	✓	✓	Tobii X2-30	-	30	iMotions software used for stimulus presentation and gaze recording	Timestudio software (Version 3.19), a MATLAB-based tool, was used for fixation duration analysis and handling dynamic stimuli.
7	[44]									The study focused on integrating machine learning techniques such as ensemble methods and oversampling to handle imbalanced data in dyslexia screening, but specific algorithms or tools related to eye-tracking data are not discussed in detail.
8	[45]	✓		✓	✓	SMI IVIEW X™ HI-SPEED (SensoMotoric Instruments)		1250	The eye movements were recorded and analyzed using SMI BeGaze 3.7 software, along with iView X 2.8	Fixation data and saccade-related information were processed using linear mixed models. Multiple measures such as fixation count, single fixation duration, first pass reading time, second pass reading time, and total fixation time were evaluated.
9	[46]	✓		✓	✓	Eyelink 1000 Plus or Eyelink Portable Duo		1000	EyeLink Data Viewer 4.2.1 (SR Research, Kanata, ON, Canada) was used for processing eye movement data	The study used various eye movement metrics such as fixation duration, first-pass reading time, regression path duration, and more. Statistical models such as linear mixed-effects models were used for data analysis.
10	[47]	✓	✓	✓	✓	Tobii X2-30	-	30	iMotions software was used for stimulus presentation and gaze recording	The Timestudio software was used to process eye-tracking data for fixation durations within specific areas of interest (AOIs).

Table 4. *Cont.*

N: 21	Reference Article	Hardware Specifications [1]							Software Specifications [2]	
		Screen-Based	Mobile	Infrared	Video-Based	Model	Resolution	Accuracy (Hz)	Platforms	Algorithms/Data Analysis
11	[48]	✓		✓	✓	Ober-2		100		Eye movement features (fixation duration, saccades) were extracted using a velocity threshold algorithm (VTA), with machine learning models (K-means clustering) used to identify severity levels of dyslexia
12	[49]	✓		✓	✓	Tobii TX300		300		The study employed reinforcement learning (RL) algorithms, specifically Q-Learning, to model and analyze eye-gaze behavior in readers with and without dyslexia. Fixation duration and saccadic movements were key metrics used in the analysis.
13	[50]	✓		✓	✓	SMI RED-m portable remote eye tracker (SensoMotoric Instruments)		60	iMotions software	The study introduced two novel features based on spatial complexity, derived from the raw eye-tracking data (x, y coordinates) to detect reading difficulties. Machine learning algorithms such as Logistic Regression (LR), Support Vector Machines (SVM), K-Nearest Neighbors (KNN), and Random Forest (RF) were used to classify dyslexic and control subjects based on these features
14	[51]	✓		✓	✓	Eyelink 2, a head-mounted mobile infrared eye tracker by SR Research	Spatial resolution of <0.04°	250		Eye-tracking data were analyzed using the Emaa software package by Ducrot et al. Saccade measures (latency, size) and refixation probability were computed. Statistical analyses included ANOVA to determine the effects of visual field and stimulus type on eye-tracking variables.
15	[52]	✓		✓	✓	Tobii Pro Eye Tracker		90	The eye movement data was processed using MATLAB	The study utilized Ordinal Pattern Transition Networks (OPTNs) to analyze reading patterns. Machine learning algorithms, including Decision Trees, Random Forest, Gaussian Naïve Bayes, and others, were applied to classify dyslexic and typically developed children based on their reading behaviors
16	[53]	✓		✓	✓	Tobii X3-120		120	Tobii Studio Pro version 3.4.8 was used to manage the reading tasks and capture eye movement data	The study used SHAP (Shapley Additive ExPlanations) to interpret the machine learning models (LightGBM) and analyze the importance of different eye-movement features such as fixation count, saccade count, gaze velocity, and more in predicting reading proficiency.

Table 4. *Cont.*

N: 21	Reference Article	Hardware Specifications [1] Screen-Based	Mobile	Infrared	Video-Based	Model	Resolution	Accuracy (Hz)	Software Specifications [2] Platforms	Algorithms/Data Analysis
17	[54]	✓		✓	✓	Eyelink 1000 Plus		1000	The eye movement data was processed and analyzed using Eyelink Data Viewer	Various eye movement measures (fixation duration, saccade amplitude, etc.) were analyzed. Statistical analysis, including mixed linear models, was used to evaluate eye-tracking data across participants.
18	[55]	✓		✓	✓	Tobii Pro Eye Tracker		90	Eye-tracking data was recorded and processed using MATLAB for analysis	Multifractal analysis was Detrended Fluctuation Analysis (DFA), and variations were analyzed using MF-DFA (Multifractal Detrended Fluctuation Analysis).
19	[56]	✓		✓	✓	Tobii Eye X		60	Clinical Eye Tracker 2020 (Thomson Software Solutions, UK)	The study utilized eye movement metrics such as the number of fixations per minute, average fixation duration, and percentage of regressions. Data analysis included measures of saccadic ability and precision, cross-referenced with subjective tests like the NSUCO and DEM.
20	[57]	✓		✓	✓	Tobii Pro X3-120	1920 × 1080	120	Eye movements were recorded and analyzed using the EEVA-S battery	The study employed algorithms to calculate various eye-tracking metrics, including fixations, visual search time (VST), recognition decision time (RDT), and the percentage of screen area searched. A fixation filter was used to analyze fixation data based on the algorithm by Engbert and Kliegl (2003). Statistical analyses included ANOVA and correlation computations.
21	[58]	✓		✓	✓	EyeLink 1000		1000	The data were processed using the Eyelink Data Viewer software from SR Research, which also handled the analysis of saccades and fixations	The study measured eye movement variables such as first fixation duration (FFD), gaze duration (GD), and saccade amplitude (SA). The data were analyzed using ANOVA to compare the performance pre- and post-intervention, focusing on how the proprioceptive intervention influenced reading patterns in dyslexic children.

[1] Hardware specifications in light grey background color. [2] Software specifications in white background color.

3.4. Cognitive, Language, and Communication Abilities Assessed (Question 4)

Following, the abilities being assessed in each study to utilize eye-tracking in dyslexia detection are established. The categorization of the abilities focusing on dyslexia-related challenges includes (i) Cognitive Abilities: Attention, Memory Recall, Visual Processing Speed, Decoding, Sequencing, Executive Function, Face Perception, Face Memory, Visual-Spatial Perception, and (ii) Language and Communication Abilities: Word Recognition, Reading Fluency, Comprehension, Vocabulary Knowledge, Phonological Awareness, Syntax and Grammar, Oral Language Skills, Pragmatics, and Social communication. This categorization can help systematically review which areas are most frequently assessed and which may need further exploration. Table 5 presents the cognitive, language, and communication abilities assessed in the studies of this review.

Table 5. Cognitive, Language, and Communication Abilities Assessed.

		Cognitive Abilities									Language and Communication Abilities								
N: 21	**Reference Article**	**Attention**	**Memory Recall**	**Visual Processing Speed**	**Decoding**	**Sequencing**	**Executive Function**	**Face Perception**	**Face Memory**	**Visual-Spatial Perception**	**Word Recognition**	**Reading Fluency**	**Comprehension**	**Vocabulary Knowledge**	**Phonological Awareness**	**Syntax and Grammar**	**Oral Language Skills**	**Pragmatics**	**Social Communication**
1	[38]	✓	✓	✓			✓	✓	✓										✓
2	[39]	✓		✓			✓				✓	✓							
3	[40]	✓		✓			✓				✓	✓	✓						
4	[41]	✓		✓			✓				✓	✓	✓						
5	[42]	✓		✓	✓		✓				✓	✓	✓						
6	[43]	✓		✓			✓				✓	✓	✓						
7	[44]	✓	✓	✓			✓				✓	✓							
8	[45]	✓	✓	✓			✓				✓	✓	✓		✓				
9	[46]	✓		✓			✓	✓			✓	✓	✓						
10	[47]	✓		✓			✓	✓		✓	✓				✓				
11	[48]	✓		✓	✓	✓					✓	✓	✓		✓				
12	[49]	✓		✓		✓					✓	✓	✓		✓				
13	[50]	✓		✓	✓		✓			✓	✓	✓	✓						
14	[51]	✓		✓	✓		✓				✓	✓	✓		✓				
15	[52]	✓		✓	✓						✓	✓	✓						
16	[53]	✓	✓	✓			✓				✓	✓	✓	✓	✓				
17	[54]	✓		✓	✓	✓	✓				✓	✓	✓		✓				
18	[55]	✓		✓		✓					✓	✓	✓						
19	[56]	✓		✓	✓	✓					✓	✓	✓		✓				
20	[57]	✓		✓			✓				✓								
21	[58]	✓		✓	✓						✓	✓	✓						

3.5. Scope of Eye-Tracking Evaluations (Question 5)

The presentation of the analysis of whether the studies focus on quantitative data (e.g., reading speed and accuracy in word recognition) or qualitative aspects (e.g., reading comprehension and engagement) provides insights into the depth and nature of the evaluations. Table 6 details the results of the eye-tracking evaluations' scope in each study included in this systematic review.

Table 6. Scope of the eye-tracking evaluations in each study of the systematic review.

N: 21	Reference Article	Quantitative Data [1]											Qualitative Data					
		Fixation Count	**Fixation Duration**	**Saccade Length**	**Saccade Count**	**Regression Count**	**Reading Speed [3]**	**Accuracy in Word Recognition**	**Blink Rate**	**Reaction Duration**	**Gaze Distribution**	**Machine Learning Performance Metrics**	**Reading Comprehension**	**Engagement**	**Emotional Response**	**Cognitive Strategies**	**Interaction with Text**	**Speed in Face Identification**
1	[38]		✓	✓					✓				✓	✓				✓
2	[39]	✓	✓				✓											
3	[40]	✓	✓		✓		✓											
4	[41]	✓	✓				✓											
5	[42]		✓		✓	✓	✓											
6	[43]		✓								✓							
7	[44]											✓						
8	[45]	✓					✓	✓					✓					
9	[46]		✓	✓	✓		✓						✓					
10	[47]						✓	✓										
11	[48]						✓	✓					✓					
12	[49]	✓	✓	✓														
13	[50]	✓	✓	✓	✓		✓	✓										
14	[51]			✓														
15	[52]		✓	✓	✓													
16	[53]						✓	✓					✓	✓				
17	[54]	✓	✓	✓	✓		✓	✓										
18	[55]		✓	✓	✓		✓											
19	[56]	✓	✓			✓	✓						✓					
20	[57]									✓								
21	[58]		✓	✓														

[1] Quantitative Data in light grey background color. [3] Words Per Minute.

3.6. Purpose of Evaluations (Question 6)

For detecting dyslexia, it is essential to identify the purpose, thus whether the studies focus on screening, assessing, or diagnosing. This distinction is crucial, as it influences the depth and thoroughness of the assessments conducted and the specific point in the diagnostic process when these evaluations are applied. The assessment covers detecting the initial signs and identifying specific patterns associated with dyslexia and implies an ongoing evaluation, which could encompass monitoring improvements. Regarding the 'purpose of evaluation' in this review, we use the terms screen (identify early signs of developmental dyslexia), assess (use diagnostic examinations and specialized procedures to investigate further and confirm developmental dyslexia in children considered at high risk based on screening and surveillance results), diagnose (to collect and analyze information from various sources, including parents, teachers, and medical professionals, along with standardized assessment tools to arrive at a diagnosis, a critical step to initiate intervention), and monitor (to conduct ongoing evaluations, which may include assessing the outcomes of interventions). Table 7 provides a detailed understanding of how the studies differ in their purpose of dyslexia evaluation.

Table 7. The purpose of evaluations performed in the studies of the systematic review is as follows.

Purpose of Evaluation	Reference Study	(%)	N: 21
Screen	[44,46,55]	14.29%	3
Assess	[38,39,42,43,45,48,51,52,54,57]	47.62%	10
Diagnose	[40,47,49,56]	19.05%	4
Monitor	[41,50,53,58]	19.05%	4

3.7. Evaluation Process Time (Question 7)

The time needed for an evaluation is a crucial aspect that provides insight into the practicality and efficiency of eye-tracking in real-world educational, clinical, or other settings. Next, Table 8 displays what authors have declared regarding process time in minutes in the 21 included studies of this review. Note that if the authors have no measurements reported on processing time, then there is no record of that paper, as shown in Table 8. Moreover, time measurements in Table 8 have been converted into minutes.

Table 8. Process Time (minutes).

N: 21	Ref Article	Preparation	Calibration	Active Evaluation	Analysis	Total
1	[38]			10 [1]		
2	[41]		27.93 (15–63) [2]			
3	[42]		40 [2]			
4	[43]				0.18	
5	[45]		30 [2]			180
6	[46]			20 [1]		
7	[51]					180
8	[57]	45–60 [3]				

[1] Time is reported for active evaluation in white background color. [2] Time is reported for calibration, and active evaluation in light grey background color. [3] Time is reported for preparation, calibration, and active evaluation in medium grey background color.

3.8. Holistic vs. Targeted Evaluations (Question 8)

We evaluate each study's assessment type to determine whether the evaluations provide a complete developmental profile or focus on specific abilities and how effectively they integrate with other diagnostic tools (e.g., EEG). This analysis addresses the comprehensiveness of the evaluation methods. Table 9 displays whether the evaluations of the included studies in this systematic review provide a holistic or targeted approach to dyslexia evaluation.

Table 9. Holistic vs. targeted evaluation.

Evaluation	Reference Study	(%)	N: 21
Holistic	-	0%	0
Targeted	[38–55,58]	100%	21

All the included studies reported targeted evaluations using eye-tracking in dyslexia detection, and it is briefly presented next.

Study [38]: Eye-tracking metrics to examine visual attention and face-processing abilities

Study [39]: The evaluation targeted reading difficulties, specifically in word recognition, fluency, and visual attention. It focused on eye-tracking data to understand reading patterns.

Study [40]: The evaluation focused on reading difficulties and visual attention. While the system can incorporate multimodal assessments, this study does not. Eye-tracking data were used to detect dyslexia rather than to create a comprehensive profile of the child's abilities.

Study [41]: This study examined reading difficulties in dyslexia, specifically visual crowding effects and reading efficiency through eye movement analysis. It focused on visual attention and reading strategies.

Study [42]: The evaluation targeted reading difficulties and visual attention, excluding holistic assessments like EEG. It focused on global reading processes and sentence-level eye movements.

Study [43]: The evaluation concentrated on visual attention and face perception without comprehensively assessing the child's cognitive or developmental profile. No multimodal tools or assessments of other cognitive functions beyond face processing and reading skills were used.

Study [44]: This study evaluated reading difficulties through task performance in gamified reading and writing exercises. It focused on improving dyslexia classification accuracy using machine learning rather than providing a comprehensive assessment with multiple data sources.

Study [45]: The evaluation focused on reading fluency, word recognition, and fixation counts without using multimodal tools like EEG. It mainly addressed visual attention and reading difficulties.

Study [46]: The study focused on using eye-tracking for dyslexia detection, integrating data with machine learning to analyze reading behaviors rather than providing a complete profile of the child.

Study [47]: This study used eye-tracking to assess visual attentional capacity and symbol processing in reading difficulties related to dyslexia. It focused on visual search abilities without incorporating other assessment tools like EEG.

Study [48]: The study concentrated on specific elements of visual attention and reading difficulties, using parameters like fixations and saccades to assess severity. It did not mention multimodal assessments.

Study [49]: This study focused on gaze fixation and reading strategies among good and poor readers. It does not address multimodal assessments like EEG and emphasizes the impact of visual attention span on reading performance in children with dyslexia.

Study [50]: The study focused on visual attention and reading difficulties, providing valuable insights from the eye-tracker to specific reading struggles, which can aid in customizing interventions.

Study [51]: The evaluation concentrated on saccade targeting strategies during reading. It lacks a comprehensive approach, such as integrating multimodal assessments like EEG, and focuses mainly on visual attention and reading difficulties, especially the initial landing position of eye movements.

Study [52]: The study targeted reading difficulties and visual attention, focusing on eye movement patterns during reading tasks without using multimodal tools.

Study [53]: Evaluations focused on visual attention and reading difficulties without emphasizing integration with other tools.

Study [54]: The study evaluated phonological and lexical-semantic processing using eye-tracking and MEG recordings. It centered on auditory word processing deficits related to dyslexia.

Study [55]: The eye-tracking evaluation focused on visual attention during reading, specifically fixation durations and saccades. It highlighted how dyslexia affects eye movements, particularly saccadic movements and fixation variability.

Study [56]: The evaluation looked at fixations and regressions in oculomotor function and their impact on reading in dyslexic children, using only eye-tracking for assessment.

Study [48]: The evaluation focused on visual selective attention (VSA) and higher-order visual functions in children with neurodevelopmental disorders like CVI, ADHD, and dyslexia. The study provided key insights into visual attention deficits.

Study [58]: This study focused on specific areas like visual attention, reading fluency, and lexical access rather than providing a comprehensive profile of the child's cognitive abilities. The proprioceptive intervention addressed multisensory integration, including proprioception.

3.9. Comparing Different Technologies and Methodologies (Question 9)

Having established the effectiveness of individual technologies and their applications, comparing the different approaches used across studies allows for identifying best practices and innovations. Table 10 presents the studies that compared various technologies and/or methodologies.

Table 10. Comparing Different Technologies and Methodologies.

Comparison of Eye-Tracking Technologies or Methodologies	Reference Study	(%)	N: 21
Different types	[40,44,46,48–50,52,57]	38.10%	8
Single type	[38,39,41–43,45,47,51,53–56,58]	61.90%	13

The texts do not discuss the relative effectiveness of different eye-tracking approaches or the comparative analysis of hardware or methodologies for studies [38,39,41–45,47,51,53–56,58].

On the other hand, the results of this review reveal the utilization of different types of eye-tracking technologies or methodologies as detailed next:

- Study [40] focused only on the SMI RED-m 120 Hz eye-tracking system but evaluated different machine learning algorithms that analyze eye movement data. It compared these algorithms for dyslexia classification rather than different hardware technologies.
- Study [44] evaluated machine learning techniques and oversampling methods (SMOTE, Borderline-SMOTE, ADASYN) to enhance dyslexia detection in imbalanced datasets rather than comparing eye-tracking technologies.
- Study [46] used **EyeLink 1000 Plus** and **EyeLink Portable Duo** to record eye movements without directly comparing different eye-tracking technologies. It was found that machine learning algorithms, like **Multi-Layer Perceptron (MLP)** and **Random Forests**, accurately predicted dyslexia by analyzing fixation patterns, saccades, and regression paths. Combining fixation data with demographic information also proved effective.
- Study [48] evaluated the effectiveness of different algorithms (VTA, K-Means) in predicting dyslexia severity levels through eye movement data.
- Study [49] compared different reading strategies (good vs. poor readers) and evaluated the effectiveness of the RL model in identifying these differences.
- Study [50] compared different sampling frequencies (60 Hz vs. 30 Hz) and targets visual attention and reading difficulties. It utilized eye-tracking data to identify specific reading struggles, aiding in developing tailored interventions.
- Study [52] compared the eye movement patterns of dyslexic and typically developing children without examining different eye-tracking technologies.
- Study [57] did not directly compare eye-tracking technologies but highlighted the Tobii Pro X3-120's effectiveness in detecting subtle gaze differences across neurodevelopmental groups. It used gaze-based parameters to provide deeper insights into visual search performance than traditional paper-and-pencil tasks.

3.10. Influence on Intervention and Educational Practices (Question 10)

This session begins by highlighting the populations involved, each study's objectives, and the evaluation's main outcomes. It then explores how these outcomes can inform and enhance interventions and practices. By examining the application of eye-tracking results in real-world settings, we can better understand their practical implications and potential benefits for future research and implementation. The author presents a detailed report in Table 11 in the relevant columns.

Table 11. Description of population aims, main outcomes, and influence on intervention and educational practices.

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
1	[38]	N: 43 children n(EG [1]): 18, n(CG [2]): 25, Grade: - Age: 9–13 years from Sweden. Dyslexia diagnosis based on word reading and phonological impairments according to the ICD-10.	Assess whether children with dyslexia show differences in face processing compared to typically developing children using eye-tracking technology to capture gaze patterns and neuropsychological measures to assess memory and speeded face identification.	The study found that children with dyslexia were not significantly different from controls in face gaze patterns, memory, or identification accuracy, but they were slower in completing the tasks. The experimental group had considerable individual variability, indicating that face-processing difficulties are not universal in dyslexia. Comment: The individual variability observed in face processing could guide future personalized approaches in both cognitive assessments and educational interventions tailored to the specific needs of children with dyslexia	The study does not propose specific interventions but suggests that improving visual attention to faces may not benefit all dyslexic children. It highlights the need for personalized intervention strategies based on individual differences in face-processing abilities.	No direct pathways to Practical Interventions.	It focused on children with dyslexia from Sweden without addressing cross-cultural applicability or linguistic differences.
2	[39]	N: 59 children n(EG): 19, n(ADHDG [3]): 21, n(CG): 19, Grade: - Mean age: 9 years from Portugal.	To investigate how word frequency and word length affect eye movements in children with dyslexia, ADHD-I, and typical readers during a silent reading task.	Children with dyslexia exhibited longer fixation durations, more frequent fixations, and higher regressive saccades than typical readers. These results align with the hypothesis that dyslexic readers process visual information more slowly and less efficiently than their peers	The results could inform interventions by highlighting specific areas of reading difficulty (e.g., longer fixation times on less familiar words), which could guide the development of targeted reading strategies or therapies.	While the study does not explicitly link evaluation results to specific interventions, the detailed reading profiles generated by the eye-tracking data could inform individualized support strategies.	Specific sample of Portuguese children. No other considerations.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
3	[40]	N: 30 children n(EG): 15, n(CG): 15, Grade: - Age: 7–13 years from Serbia.	To develop a spatiotemporal feature set for improved detection of dyslexic reading patterns in Serbian-speaking children.	The study achieved a 94% accuracy in classifying dyslexic and non-dyslexic participants using the proposed features and machine learning models.	The outcomes may influence intervention strategies by highlighting fixation complexity as a key indicator of reading difficulties, guiding targeted interventions for children with dyslexia.	No direct pathways to Practical Interventions.	The study examined Serbian-speaking children and did not address cultural diversity, highlighting challenges in diagnosing dyslexia in languages like Serbian.
4	[41]	N: 70 children n(EG): 38, n(CG): 32, Grade: - Age: 10–14 years from Poland.	The aim was to investigate the effect of inter-letter spacing on reading accuracy, speed, and eye movement patterns in children with and without dyslexia.	The study found that increased inter-letter spacing did not significantly affect reading accuracy or comprehension in either group. However, increased spacing led to shorter fixation durations in dyslexic children, suggesting some reduction in visual processing effort.	Adjusting inter-letter spacing may boost reading fluency in children with dyslexia, but the effects on overall reading ability and comprehension are limited.	No direct pathways to Practical Interventions.	The study overlooked cultural and linguistic diversity, focusing only on Polish-speaking children. It did not address how the results might apply to other populations or how demographic factors could influence the findings.
5	[42]	N: 144 children n(EG): 72, n(CG): 72, Grade: 1–5 Age: 10–14 years from Poland.	The aim was to compare global reading processes between children with and without reading difficulties using eye-tracking data.	Children at high risk for dyslexia had longer fixation durations and slower reading speeds, especially with longer, less common words, lagging 2 to 3 years behind their typically developing peers in reading abilities.	The outcomes suggest that targeted interventions to improve word recognition and reading fluency could be beneficial for children with dyslexia.	No direct pathways to Practical Interventions	The study focused on Russian-speaking children and does not explicitly consider other linguistic or cultural backgrounds. Therefore, the generalizability of the results to different populations is not addressed in this study.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
6	[43]	N: 43 children n(EG): 18, n(CG): 25, Grade: - Age: 9–13 years from Sweden	Left visual field bias during face perception is present in children with dyslexia, and to explore the association between this bias and word reading skills.	The study found that children with dyslexia did not exhibit the typical left visual field bias when viewing faces, whereas controls did. Additionally, the strength of the left visual field bias correlated with better word reading skills in controls but not in dyslexic children.	The study suggests that atypical hemispheric lateralization for face processing may be linked to word reading difficulties in dyslexia, but it does not directly propose intervention strategies based on these findings.	No direct pathways to Practical Interventions.	The study did not explicitly consider cultural or linguistic diversity. The findings were based on a homogenous sample of Swedish-speaking children, and the generalizability to other populations is not addressed.
7	[44]	N: 3644 participants n(EG): - n(CG): - Grade: - Age: -	To improve dyslexia detection by addressing the class imbalance issue using machine learning and oversampling techniques.	The study significantly improved dyslexia detection accuracy using the combination of oversampling and ensemble learning techniques. The recall rate (ability to correctly identify dyslexic participants) increased significantly.	The outcomes suggest that machine learning models, particularly those incorporating oversampling, can improve early detection and intervention for dyslexia by identifying potential cases more accurately during pre-screening.	No direct pathways to Practical Interventions.	The study does not explicitly address cultural or linguistic diversity beyond the mention of dyslexic populations. There is no discussion of how demographic variables such as age, culture, or language influence the generalizability or accuracy of the evaluations.
8	[45]	N: 59 children n(EG): 19, n(ADHDG): 21, n(CG): 19, Grade: - Mean age: 9 years from Portugal.	To predict reading difficulties using cognitive and eye-tracking data, specifically to differentiate between dyslexia and ADHD-I.	Children with dyslexia had more fixations and longer reading times compared to typical readers. Dyslexic children also demonstrated difficulties in phonological processing.	The results support targeted interventions aimed at improving reading fluency and attention control in children with dyslexia and ADHD-I.	Direct pathways to Practical Interventions. - Contribute significantly to understanding how cognitive factors and eye movement data can be used to predict and differentiate dyslexia and ADHD-I.	The study focused on a homogeneous sample of Portuguese-speaking children, and there was no discussion of cultural or linguistic diversity. Thus, the findings are not necessarily generalizable to other populations.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
9	[46]	N: n(EG): - n(CG): - Grade: school-aged children Age: -	The primary goal of the study was to detect dyslexia using eye-tracking data in combination with demographic information through machine learning models.	The study found that eye-tracking data combined with AI models, such as Random Forest and Multi-Layer Perceptron (MLP), can achieve high accuracy in detecting dyslexia. The study supports the use of eye-tracking technology as an early screening tool for dyslexia, potentially influencing intervention strategies by identifying children who need additional educational support.	The study's outcomes have implications for educational practices.	Providing pathways to develop interventions based on early detection of reading impairments through eye movement data.	The study examined diverse populations by age and education but did not address cultural or linguistic backgrounds. It considers age as a demographic variable, influencing the classification of evaluation results. The study suggests that combining demographic data with eye-tracking can improve dyslexia detection accuracy across different age groups.
10	[47]	N: n(EG): - n(CG): - Grade: school-aged children Age: -	The primary aim was to investigate visuo-attentional capacities and their impact on reading difficulties, particularly in identifying and processing symbols that resemble letters.	The study found that children with dyslexia exhibited reduced visuo-attentional spans, which hindered their ability to process multiple visual stimuli simultaneously. These deficits were linked to slower visual search speeds, particularly for letter-like stimuli.	The outcomes suggest that targeting visuo-attentional training could benefit children with dyslexia. By identifying these specific visual deficits early, interventions could be designed to improve their reading skills.	The study connects eye-tracking results to interventions by identifying visual attention deficits that affect reading, guiding the development of training programs to enhance children's visual processing skills.	The study does not address cultural or linguistic diversity in its sample, focusing primarily on children with dyslexia. While the findings may be relevant to various groups due to the universal nature of visuo-attentional deficits, the lack of attention to linguistic or cultural factors could limit its applicability to non-Western populations. Overall, the insights improve our understanding of visual processing challenges in children with dyslexia and suggest targeted interventions.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
11	[48]	N: 185 n(EG): 97 n(CG): 88 Grade: - Age: 9–10-year-olds	To assess and predict dyslexia severity levels based on eye movement data using machine learning models.	- Dyslexics tend to have more fixations, fewer saccades, and more regressions. - The research successfully used machine learning models to classify severity into high and low dyslexia levels.	The outcomes could influence tailored intervention strategies, such as focusing on improving visual processing speed and word decoding in children with high dyslexia severity.	No direct pathways to Practical Interventions.	The study focused on children aged 9 to 10 years from similar cultural and linguistic backgrounds. Generalizability to other populations isn't addressed but is suggested as a future research area.
12	[49]	N: 20 n(EG): 5 n(CG): 15 Grade: - Age: ~7-year-olds	The study aims to model eye-gaze behavior during reading to differentiate between good and poor readers and help in the early detection of dyslexia.	The study finds that fixation durations and scanpath lengths are significantly different between dyslexic and non-dyslexic readers, with poor readers showing longer fixation durations and revisiting words more frequently	The outcomes suggest that targeted reading interventions could be designed based on identified reading strategies.	The study identifies ineffective reading strategies, setting the stage for future educational or therapeutic interventions to improve reading skills.	The study does not address diverse populations regarding age, culture, or language. Its findings are based on 7-year-old children, limiting generalizability to other groups. However, the methodology could be adapted with suitable adjustments.
13	[50]	N: 30 Serbian children n(EG): 15 n(CG): 15 Grade: - Age: 7–13-year-olds.	To differentiate dyslexic from neurotypical children based on new eye-tracking features and examine the influence of text color configurations on reading performance.	The eye-tracking features, especially those detecting vertical alteration scores (VAS), were successful in separating dyslexic readers from controls. The best accuracy achieved was 88.9% (60 Hz) and 87.8% (30 Hz).	The results suggest that real-time feedback on reading performance could be useful for interventions, particularly in personalized text presentation configurations.	Yes, there are clear pathways linking the evaluation results to practical interventions, especially in terms of modifying reading conditions (e.g., background colors).	The study focused on Serbian children and suggests that its findings might apply to other languages, but further research is needed to assess accuracy across different cultures and languages. It also highlights the importance of personalized approaches to text presentation, though it does not explore how demographic factors like age or cultural background influence the results.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
14	[51]	N: 61 French-speaking children n(EG): 21 n(CG): 20 n(NF1G [4]): 20 Grade: - Age: 8–12-year-olds	The aim was to examine saccade targeting strategies during reading tasks and investigate the differences in eye movement behavior between children with and without reading disorders.	Children with DD exhibited more refixations, longer saccades, and atypical initial landing positions compared to typically developing children. The results suggest that eye movement differences are linked to the reduced reading experience rather than being a direct cause of dyslexia.	The findings indicate that interventions targeting oculomotor behavior and visual attention may help improve reading performance in dyslexic children.	No direct pathways to Practical Interventions.	The study included a diverse group of children: those with developmental dyslexia, neurofibromatosis type 1 (NF1), and typically developing peers, although it mainly focused on French-speaking children without exploring broader cultural or linguistic diversity. Reading experience and neurological conditions impacted evaluation accuracy. Children with poor reading skills exhibited less precise saccade targeting, highlighting the need to consider individual differences in proficiency.
15	[52]	N: 43 Spanish-speaking children n(EG): 14 n(CG): 29 Grade: - Age: 9–10-year-olds.	The aim was to detect reading difficulties in children using eye-tracking and ordinal pattern transition networks (OPTNs).	Dyslexic children exhibited different eMovement patterns that were compared to typically developing children. Machine learning models like Decision Trees and Random Forest achieved 100% accuracy in classification between the two groups).	The results could help develop interventions that focus on improving eye movement control and reading strategies for dyslexic children.	The study demonstrates how eye-tracking results can be used to inform interventions, particularly by analyzing specific reading behaviors.	The study involved a homogeneous group of Spanish-speaking children from Argentina. While the results are promising, they do not thoroughly address how cultural or linguistic diversity might affect them. Additionally, findings may be specific to the 9 to 10 age group

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
16	[53]	N: - n(EG): - n(CG): - Grade: - Age: - Children with dyslexia or ADHD and controls.	To identify cognitive and linguistic deficits in dyslexia using eye-tracking.	Eye-tracking provides insights into attention mechanisms and phonological processing in dyslexic children, which can influence interventions.			The literature has limited discussion on cultural and linguistic diversity, with most studies focusing on European populations. The generalizability of findings across different backgrounds is not well analyzed. This summary highlights key points on technology, cognitive abilities, and methods for detecting dyslexia through eye-tracking.
17	[54]	N: 28 Spanish-speaking n(EG): 14 n(CG): 14 Grade: - Age: 12+ years old	The main aim is to link phonological deficits in dyslexia to cortical responses during spoken word processing.	Dyslexic readers showed reduced cortical responses to phonological and lexical information. Phonological skills significantly influence neural responses to spoken words.	The results suggest that phonological training could benefit dyslexic readers by improving processing at multiple linguistic levels.	The study highlights the need for phonological interventions but does not provide specific intervention pathways	The study focused solely on Spanish speakers and did not address other cultural or linguistic backgrounds. However, it highlights that reduced phonological processing ability is relevant across neurodiverse populations, offering a clear understanding of the eye-tracking methods used.
18	[55]	N: - n(EG): - n(CG): - Grade: - Age: 9–10 years old.	To investigate the fractal characteristics of eye movements during reading in children with and without dyslexia.	Children with dyslexia exhibited less complex fractal structures and lower long-range correlation in their eye movements compared to typically developed children. These differences highlight potential neurocognitive challenges in reading due to dyslexia.	The findings suggest that fractal analysis could be a useful tool for early detection of reading disorders, helping to tailor interventions for children with dyslexia.	The results could inform strategies to improve reading fluency and attention in dyslexic children by targeting specific eye movement patterns.	The study considered biological sex, ethnicity, and other demographic factors, ensuring a balance between the dyslexic and typically developing groups. However, it did not address how these factors influenced the evaluation's accuracy.

Table 11. *Cont.*

N: 21	Reference Article	Population	Aim	Outcomes	Influence on Intervention and Educational Practices	Clear Pathways to Interventions	Consideration of Diverse Populations
19	[56]	N: 68 n(NDDG [5]): 24 n(OAG [6]): 24 n(CG): 20 Grade: - Age: 6–12 years old.	To assess oculomotor function during reading in children with NDD compared to healthy controls.	Children with NDD exhibited more frequent regressions, longer fixation durations, and longer reading times than controls. These oculomotor deficits negatively impacted reading fluency and comprehension.	The findings suggest that interventions targeting oculomotor function, such as visual therapy, may improve reading outcomes for children with NDD.	The study demonstrates how eye-tracking data can identify specific reading difficulties, which could inform individualized educational and therapeutic interventions.	The study does not address cultural or linguistic diversity. Focusing on children aged 6 to 12 with neurodevelopmental disorders, the study does not explore how cultural or linguistic backgrounds influence eye-tracking results, though age and developmental stage were considered important for assessing reading abilities.
20	[57]	N: 126 n(EG): 28 n(CVIG [7]): 22 n(ADHDG): 32 n(OG): 44 Grade: - Age: 6–12 years old.	The study aimed to explore how gaze-based visual search characteristics could distinguish children with CVI from those with ADHD, dyslexia, and neurotypical development.	Children with CVI had significantly impaired visual search performance compared to all other groups. The study provided evidence that visual search deficits in CVI are associated with higher-order visual function deficits.	The outcomes emphasized the need for individualized interventions, particularly for children with CVI, to improve visual search performance.	Adaptations in educational settings (e.g., using structured visual materials) may also be required for children with CVI.	The study noted variations in visual search performance among populations but did not thoroughly investigate cultural or linguistic diversity. It primarily involved Dutch children, and implications for more diverse groups were not assessed.
21	[58]	N: 19 n(PSIG [8]): - n(STG [9]): - Grade: - Age: 9–14 years old.	To examine the effects of proprioceptive intervention on reading performance and eye movements in children with developmental dyslexia.	The PSI group showed significant improvements in reading fluency, smoother eye movements, and faster lexical access. These improvements were not observed in the ST group alone.	The study suggests that proprioceptive interventions can complement traditional speech therapy to improve reading performance in children with dyslexia.	No direct pathways to Practical Interventions.	The study does not address the generalizability of results beyond French-speaking children with developmental dyslexia. It is uncertain how these findings apply to children from different cultural or linguistic backgrounds, indicating a need for further research on the influence of demographic variables on eye-tracking evaluations.

[1] EG—Experimental Group. [2] CG—Control Group. [3] ADHDG—Attention Deficit Hyperactivity Disorder Group. [4] NF1G—Neurofibromatosis type 1 Group. [5] NDDG—Neurodevelopmental Disorders Group. [6] OAG—Oculomotor Anomalies Group but without NDD. [7] CVIG—Cerebral Visual Impairment Group. [8] PSIG—Proprioceptive and Speech Intervention Group. [9] STG—Speech Therapy Group.

3.11. Population Diversity and Generalizability (Question 11)

Finally, we explore whether the studies account for diverse populations. This addresses the applicability and inclusivity of the research findings and closes the loop on whether the technology and evaluations are generalizable across different groups. The results of this population diversity and generalizability are displayed in depth in Table 11 in the last column for all included studies in this systematic review.

4. Discussion

The current study aims to systematically review the use of eye-tracking technology in detecting dyslexia in children, providing a critical analysis of its effectiveness across different sectors, technological tools, and cognitive assessments during the last three years. It focuses on hardware and software platforms used in dyslexia detection and explores the extent to which eye-tracking technology has been applied to assess specific cognitive, language, and communication abilities, such as reading fluency, phonological awareness, and visual processing speed. Additionally, it examines the primary purposes of these evaluations, ranging from screening to diagnosing dyslexia, and assesses these methods' time and practical implications. This review offers insights into how these evaluations influence interventions, educational practices, and future research. The study addresses key gaps in eye-tracking research by categorizing the diverse approaches and technological methodologies used in dyslexia detection.

A structured discussion based on the findings across the different studies will address each key question.

4.1. Geographic Distribution Results

The results of this systematic review reveal that France stands out with the highest number of studies, suggesting a concentrated interest in dyslexia-related research in this region. Countries like Argentina, India, Portugal, Russia, Serbia, and Sweden follow in contributed studies, reflecting emerging or established research efforts in these regions, and other nations like Australia, Netherlands, Singapore, Spain, and the UK each contributed one study, showing broader, though less concentrated, engagement in the field. This distribution reflects an international effort to address dyslexia through eye-tracking research, with Europe contributing many studies.

4.2. Sectoral Classification Results

The findings of this review indicate that clinical applications of eye-tracking dominate the field, accounting for nearly half of the studies reviewed. This highlights its increasing significance in medical and psychological assessments. In the educational sector, eye-tracking enhances our understanding of learning challenges and improves instructional methods for students with dyslexia. Meanwhile, the computer science and engineering sector emphasizes the importance of technological advancements in processing and analyzing eye-tracking data, which supports the development of assistive tools and diagnostic systems. This classification shows the diverse potential of eye-tracking research and its application across sectors aimed at diagnosing, understanding, and improving dyslexia and related reading difficulties.

4.3. Specific Types of Eye-Tracking Technology Results

The systematic review highlights the diverse range of hardware and software technologies used in eye-tracking studies for dyslexia assessment. These tools vary in resolution, accuracy, and the type of data analysis performed, reflecting the technological diversity within the field.

Regarding hardware, most studies utilized screen-based eye trackers, such as the Tobii series (e.g., Tobii X2-30, Tobii TX300, and Tobii Pro), SMI models, and EyeLink devices. In contrast, only a few studies incorporated mobile eye trackers, typically for participants needing freedom of movement or head-mounted tasks, such as the EyeLink 2. Most studies favored infrared tracking technology for its precision in capturing eye movements, which is essential for high-accuracy tracking in clinical and research applications. Some studies relied on video-based systems, like the Tobii X2-30, which offer lower accuracy. The accuracy of the eye trackers varied significantly, ranging from 30 Hz (e.g., Tobii X2-30) to 1000 Hz (e.g., EyeLink 1000 Plus). Higher accuracy devices were primarily used in clinical settings to detect subtle differences in reading patterns. In contrast, lower accuracy systems were more commonly employed in educational contexts, where extreme precision may be less critical.

For software, platforms such as Tobii Studio, iMotions, and SR Research EyeLink Data Viewer were frequently used to record and analyze eye movements. To process the data, studies utilized various tools, including MATLAB, Python, and SPSS, with several incorporating machine learning algorithms (such as Logistic Regression, Support Vector Machines, and K-Nearest Neighbors) to differentiate between dyslexic and typical reading patterns.

Therefore, highly accurate infrared eye trackers are the preferred choice for clinical research, providing the precision needed for detailed dyslexia assessments. In contrast, less accurate but more accessible technologies are often used in educational settings. The combination of advanced software platforms and modern data analysis techniques, including machine learning, enhances the capabilities of eye-tracking research. By integrating traditional statistical methods with these computational tools, researchers can improve the accuracy of dyslexia detection, enabling the development of more personalized interventions that cater to individual reading needs. This highlights the balance between accessibility and precision across different sectors, demonstrating the versatile application of eye-tracking technologies in both research and practical educational environments.

4.4. Cognitive, Language, and Communication Abilities Assessed

The studies reviewed systematically assess various cognitive, language, and communication abilities through eye-tracking technology, primarily focusing on dyslexia-related challenges.

The most frequently assessed cognitive abilities across the studies include: (i) Attention: All studies evaluated attention, as indicated by eye movement patterns such as fixation durations and saccadic activity, which are key to understanding how dyslexic individuals maintain focus during reading tasks; (ii) Visual Processing Speed: Eye-tracking studies often measured the speed at which visual information is processed by tracking the time spent on each word or area of interest, highlighting difficulties in quick visual comprehension for dyslexic readers; (iii) Decoding and Sequencing: Some studies focused on decoding words and the sequential processing of text, which are vital in understanding how dyslexic individuals struggle with fluent word recognition and organizing text; and (iv) Face Perception and Memory: A few studies extended beyond traditional reading tasks to explore dyslexic children's face perception and memory, linking visual and memory deficits in dyslexia with broader cognitive challenges.

Key language and communication abilities assessed include: (i) Word Recognition and Reading Fluency: Nearly all studies focused on word recognition and fluency, using eye-tracking data to observe how dyslexic readers engage with text, how frequently they fixate on words, and how many regressions (backtracking to previous words) occur during reading, (ii) Comprehension: Some studies examined how dyslexic individuals comprehend text by analyzing fixation duration on critical words and areas, as well as tracking the length of time spent on re-reading or skimming, (iii) Phonological Awareness and Vocabulary Knowledge: Eye-tracking studies also explored phonological processing, particularly how dyslexic readers handle sound-to-letter matching, which is key in diagnosing phonological deficits: and (iv) Syntax, Grammar, and Oral Language Skills: Fewer studies examined higher-level language skills, such as syntax, grammar, or oral language skills, indicating potential areas for future exploration.

The systematic review reveals that attention, visual processing speed, and word recognition are the most assessed abilities in eye-tracking studies for dyslexia detection.

These abilities are critical in diagnosing dyslexia, as dyslexic readers often exhibit slower processing speeds, more fixations, and difficulties maintaining attention during reading tasks. Comprehension, phonological awareness, and reading fluency are also frequently explored, providing deeper insights into the core language deficits associated with dyslexia. However, certain areas, such as syntax, oral language skills, and social communication, remain less explored in the studies reviewed. These areas could be valuable in understanding the broader communicative challenges faced by dyslexic individuals, suggesting that future research might benefit from expanding the scope of eye-tracking assessments to include these domains. Overall, the review highlights the comprehensive application of eye-tracking technology in measuring various cognitive and language abilities essential to understanding dyslexia. These insights can enhance targeted interventions, improve diagnostic tools, and provide a more holistic view of dyslexic challenges, though further exploration of underrepresented abilities is encouraged.

4.5. Results on the Scope of Eye-Tracking in Assessing Dyslexia

The results of this systematic review show that the scope of most eye-tracking studies on assessing dyslexia focuses on quantitative data, such as fixation count, fixation duration, saccade length, and reading speed. These metrics are widely used to assess how dyslexic individuals visually process text. For example, studies consistently measure fixation duration [38,39], as dyslexic readers tend to fixate longer on words than their peers. Saccades [40,42] and reading speed [41,45] (e.g., [32,36]) are also key indicators of reading difficulties, with slower reading speeds and shorter saccades reflecting challenges in recognizing and processing words. In addition to these quantitative metrics, some studies incorporate qualitative assessments, such as reading comprehension, engagement, and emotional responses [38,53]. These measures provide a broader understanding of how dyslexic readers interact with text on a cognitive and emotional level. For instance, studies exploring engagement and comprehension highlight the deeper struggles dyslexic individuals face beyond mere reading speed, offering insights into how they process and understand the material.

While quantitative data are the primary focus, qualitative aspects are gaining attention as they contribute to a holistic understanding of dyslexia. Future research could benefit from integrating both approaches to better capture the full range of challenges faced by dyslexic readers and to develop more effective, personalized interventions.

4.6. Results on the Primary Purpose of Eye-Tracking Evaluations

The systematic review classifies the purpose of dyslexia evaluations into four categories: screening, assessing, diagnosing, and monitoring. Each serves a specific role in assessing dyslexia and impacts the depth and timing of the evaluation.

Almost half of the studies focused on assessment, involving detailed diagnostic examinations to confirm dyslexia in high-risk children, such as studies [38,39,42]. The diagnosis was the purpose in nearly one out of five studies aimed at formal diagnoses using data from standardized tests and reports from teachers and parents like studies [40,49]. Screening, almost one out of 7 studies, targeted early identification of dyslexia while monitoring roughly one out of five studies tracked the impact of interventions and reading progress over time.

The focus on assessment shows that detailed diagnostic evaluations are the primary research interest. However, fewer studies address screening despite its importance for early detection. The review suggests a need for more balanced attention across all stages, including screening and monitoring, to enhance early intervention and track dyslexia progression.

4.7. Results on Reporting Time Required for Eye-Tracking Evaluation

The findings of this study of process time for eye-tracking evaluation recording in the included studies highlight significant variation in the time required for different phases of the evaluation process. Notably, active evaluation times varied widely, with some studies reporting durations as short as 0.18 min [43], while others extended up to 180 min [45,51]. This wide range indicates that the complexity and depth of the evaluation greatly influence the time required. Preparation and calibration times were reported in fewer studies, suggesting that not all researchers accounted for the time spent setting up the experiment. For example, preparation times ranged from 30 min [45] to 45–60 min [57], and calibration times varied between 10–40 min [38,42]. Interestingly, analysis times were not consistently reported, a significant omission, as it is a critical step in transforming raw eye-tracking data into meaningful insights. Only a few studies, such as [45], provided a total evaluation time, emphasizing the need for greater transparency in reporting these details to better assess the practicality and efficiency of eye-tracking in real-world settings.

The evaluation process time varies significantly depending on the study design, complexity, and depth of the assessment. Longer evaluation times, especially for active evaluations, suggest a more detailed analysis, but the lack of consistent reporting on calibration and analysis times presents challenges in fully assessing the practicality of eye-tracking evaluations in real-world educational or clinical settings. More comprehensive reporting on these time elements would help educators and clinicians understand the feasibility of implementing these assessments.

4.8. Results on the Holistic vs. Targeted Evaluations

The systematic review results clearly show that all 21 studies conducted targeted evaluations, with none offering a holistic assessment of dyslexia using eye-tracking. This means the studies primarily focused on specific abilities, such as visual attention, reading difficulties, and word recognition, without integrating other cognitive or sensory assessments (e.g., EEG, auditory processing). The studies tended to concentrate specifically on particular aspects of reading behavior, like fixation duration, saccade length, or face perception [38,43], aiming to measure these specific parameters rather than providing a comprehensive profile of the child's overall developmental and cognitive abilities. For instance, many studies [39,42,45] focused on reading fluency and word recognition, while others, like [44,46], integrated machine learning for dyslexia classification based on eye-tracking data. However, these evaluations were still narrow in scope, addressing only certain aspects of reading and visual attention. Studies that considered additional cognitive dimensions, such as phonological awareness or lexical processing, also tended to remain focused on specific domains rather than expanding into a broader assessment.

These findings reveal that all studies were targeted, focusing on specific cognitive and language abilities related to dyslexia rather than providing a holistic evaluation. This targeted approach is beneficial for addressing specific research questions, but it limits the broader understanding of how the deficits of dyslexia interact with other cognitive or sensory functions. Expanding future research to include multimodal tools (e.g., combining eye-tracking with EEG or auditory assessments) could offer a more comprehensive understanding of dyslexia and related cognitive deficits, potentially leading to more effective and personalized interventions.

4.9. Results on Comparison of Different Technologies or Methodologies

The study comparing different technologies and methodologies for eye-tracking in dyslexia detection shows that almost two out of five studies compared different technologies or methodologies. At the same time, the majority used a single type of eye-tracking technology without exploring alternatives. Many studies focused not on hardware comparison but on comparing data analysis methodologies and machine learning algorithms to enhance dyslexia detection.

Studies like [40,44,48] focused on comparing machine learning algorithms and data processing techniques rather than the hardware. For instance, ref. [40] utilized the SMI RED-m 120 Hz eye tracker but compared the performance of algorithms like Logistic Regression, K-Nearest Neighbors, and Support Vector Machines for classifying dyslexia, highlighting that software and data processing techniques can significantly impact the accuracy of dyslexia classification. Similar oversampling techniques like SMOTE and ADASYN were used to improve the classification of dyslexia in imbalanced datasets, showcasing the importance of the method used to analyze eye-tracking data rather than the eye-tracking device [44]. Very few studies explicitly compared eye-tracking hardware. For instance, [50] evaluated the impact of different sampling frequencies (60 Hz vs. 30 Hz) on visual attention data, suggesting that higher sampling rates provide better data resolution for detecting subtle reading difficulties.

However, most studies focused on a single eye-tracking technology, such as Tobii or EyeLink, rather than comparing different devices directly. The emphasis was primarily on using these technologies to collect and analyze data rather than determining the most effective hardware for dyslexia detection.

Studies like [46,52] explored how machine learning models, such as Multi-Layer Perceptron and Random Forests, can analyze eye-tracking data (e.g., fixation patterns, saccades, regression paths) to predict dyslexia accurately. This underscores that advancements in data analysis methodologies—including combining eye-tracking data with demographic information—can significantly improve dyslexia detection without necessarily needing different hardware technologies.

In contrast, ref. [56] used the Tobii Pro X3-120 eye tracker and highlighted its effectiveness in capturing subtle gaze differences across neurodevelopmental groups but did not compare it with other technologies. The study emphasized that eye-tracking devices can provide deeper insights into reading challenges than traditional diagnostic tools.

Most studies in the review did not directly compare different eye-tracking devices. Instead, they compared data analysis techniques or machine learning models that utilize eye-tracking data. This suggests that the effectiveness of dyslexia detection relies more on how the data is processed and interpreted rather than on the specific eye-tracking hardware used. However, the few studies that did explore different hardware aspects, such as sampling frequency, indicated that higher precision in eye-tracking data collection could improve the detection of subtle dyslexic reading behaviors.

Overall, future research could benefit from more direct comparisons of eye-tracking hardware to establish best practices and potentially optimize dyslexia detection through more suitable technologies. Combining advanced data processing techniques with comprehensive hardware comparisons could lead to even more accurate and efficient methodologies for dyslexia diagnosis.

4.10. Results on Population, Aims, Main Outcomes, and Influence on Intervention and Educational Practices

4.10.1. Population

The total number of participants across the 21 studies included in this systematic review was 4611 children. The sample sizes varied significantly, ranging from 19 participants [58] to 3644 participants [44]. These populations primarily consisted of school-aged children between 6 and 14 years old. Most participants were diagnosed with dyslexia or related conditions for comparative purposes, such as ADHD, neurodevelopmental disorders (NDD), or cerebral visual impairment (CVI).

The studies were predominantly conducted in European countries, including Sweden, Portugal, Serbia, and Poland, with little focus on other cultural or linguistic backgrounds. Overall, the studies showed a lack of demographic diversity, with only a few considering the influence of factors like age. None systematically addressed differences based on ethnicity, language, or socioeconomic background.

4.10.2. Aims

The primary aim of these studies was to assess dyslexia using eye-tracking technology by analyzing reading difficulties and abnormal eye movements, such as fixations, saccades, and regressions. Several studies focused on improving the accuracy of dyslexia detection through machine learning models [40,44,46], while others investigated specific reading behaviors [38,39,47]. Some research explored the effectiveness of interventions for enhancing reading fluency, including a study on proprioceptive therapy [58]. Additional studies examined reading strategies and the impact of visual processing deficits on children with dyslexia [39,45]. A subset of studies aimed to differentiate between proficient and struggling readers, assessing how various cognitive processes—such as attention, face processing, and phonological awareness—affect the performance of dyslexic individuals [38,54].

4.10.3. Main Outcomes

Most studies indicate that children with dyslexia exhibit longer fixation durations, more frequent regressions, and slower reading speeds than their peers without dyslexia. These findings are consistent across various research, such as studies [30,36,43], which show that reading efficiency and word recognition are generally impaired in children with dyslexia and are also in line with research not included in this systematic review [59,60].

Research has also highlighted the effectiveness of machine learning models in identifying dyslexic patterns, achieving high classification accuracy—ranging from 94% in the study [40] to 100% in the study [52]. Furthermore, investigations into interventions, such as proprioceptive training [58], have demonstrated significant improvements in reading fluency and smoother eye movements, emphasizing the potential of targeted interventions to enhance reading performance.

Additionally, other studies have pointed out that visual processing deficits, including difficulties with gaze-based visual search and visuo-attentional capacities, contribute to the reading challenges encountered by children with dyslexia [47,58].

4.10.4. Influence on Intervention and Educational Practices

The outcomes of these studies have significant implications for educational interventions. By identifying specific reading difficulties, such as longer fixation times or frequent regressions, educators and clinicians can design targeted interventions to address these challenges. For example, findings related to the impact of word frequency and length on eye movements [39] can inform reading strategies that focus on improving visual processing speed and word recognition in dyslexic children. Moreover, the studies highlight the potential of using machine learning models [40,44] to enhance the early detection of dyslexia, which could lead to earlier and more effective interventions. However, while the results suggest pathways for intervention, many studies stop short of fully exploring how these insights can be translated into specific practical applications within classroom or clinical settings.

4.11. Results on Clear Pathways to Interventions

Although several studies suggest their findings could inform educational or clinical practices, few offer clear pathways to practical interventions. Studies such as [50], which propose real-time feedback based on eye-tracking data, show the potential for personalized interventions to improve reading performance. Similarly, using visual therapy to improve oculomotor function in children with neurodevelopmental disorders [56] points to practical applications that could be explored further. In contrast, despite highlighting the importance of early detection and intervention, many studies do not provide direct links to actionable educational or therapeutic strategies. Studies like [48,58] discuss the implications of their findings but fail to offer specific guidance on implementing these results in real-world settings.

The review of these studies reveals that while eye-tracking technology offers valuable insights into the reading behaviors of children with dyslexia, there are several areas where improvements can be made. Most studies highlight the efficacy of targeted interventions based on eye-tracking data but often fall short of providing clear implementation strategies. Furthermore, the limited consideration of diverse populations indicates a need for future research to explore how dyslexia manifests across different cultural and linguistic groups, ensuring the findings can be more broadly applicable.

4.12. Practical Implications for Educators and Clinicians

The findings from this review offer significant practical insights for educators and clinicians working with dyslexic children. Eye-tracking data reveal individual reading patterns—such as fixation durations and saccadic movements—which can guide personalized instructional adjustments, such as text size, spacing, or complexity. In adaptive learning, these insights allow educators to tailor reading materials to align with each child's processing speed and comprehension levels, fostering inclusivity and differentiated instruction in the classroom.

In clinical settings, eye-tracking serves as an effective early screening tool, identifying potential reading challenges through indicators like excessive fixations and regressions before formal diagnosis. This allows for timely interventions, such as phonological awareness training, to address reading challenges early. Additionally, eye-tracking provides objective measures of intervention effectiveness, enabling clinicians and educators to monitor progress based on measurable improvements in reading speed, fixation reduction, and smoother saccadic patterns, allowing for evidence-based adjustments to intervention strategies.

Eye-tracking technology also supports inclusive Universal Design for Learning (UDL) practices by allowing educators to recognize and address dyslexic students' specific reading challenges. Strategies such as multimodal reading formats, visual aids, and interactive reading tools help dyslexic readers engage without needing specialized programs. The integration of eye-tracking data with machine learning can further enhance assistive tools, providing real-time feedback such as highlighting difficult words or offering phonetic cues, allowing dyslexic readers greater independence.

Figure 3 presents the proposed model for a standardized eye-tracking workflow in dyslexia evaluation, detailing each stage from equipment selection to data analysis. This model aims to enhance consistency and transparency in eye-tracking applications, supporting the systematic collection and reporting of eye-tracking data, which can inform future intervention strategies.

Figure 3. Comprehensive Workflow for Eye-Tracking Evaluation in Dyslexia Detection and Intervention.

4.13. Limitations

A limitation of this systematic review is the absence of a formal review protocol. Although the authors address this issue by following standard systematic review guidelines, specifically the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement, the lack of a predefined protocol could introduce methodological inconsistencies. While the PRISMA guidelines provide essential reporting elements to ensure transparency and consistency, not having an established protocol may still impact the reproducibility and comprehensiveness of the review process.

Another key limitation is that a single reviewer conducted the screening and study selection. Although efforts were made to maintain objectivity—through strict adherence to predefined criteria, pilot screening, and consultations with experts—there is an inherent risk of selection bias. The absence of independent verification may have influenced decisions regarding which studies were included or excluded, potentially affecting the overall comprehensiveness of the review. Future reviews would benefit from involving multiple reviewers to reduce bias and ensure a more robust screening process.

Additionally, the review excludes studies in non-alphabetic languages, such as Chinese and Arabic, which narrows the scope of the findings. However, this limitation is acknowledged as the focus on alphabetic orthographies allows for a more coherent analysis of dyslexia detection using eye-tracking methods. While some fundamental reading principles may apply universally, significant differences exist in mastering non-alphabetic systems—such as grapheme-phoneme mapping—suggesting that alphabetic systems require specific consideration. This approach aims to avoid introducing complexities from fundamentally different reading systems, like ideographic or syllabic scripts. Nonetheless, focusing solely on alphabetic writing systems may limit how we understand dyslexia in other types of writing. This approach might miss important ways in which dyslexia appears in different languages. Future reviews should investigate these issues to provide a better understanding of how dyslexia manifests across various writing systems.

Moreover, limitations of eye-tracking technology in dyslexia assessment must be recorded. Eye-tracking technology, while promising, has limitations. The high costs and need for technical expertise restrict accessibility, particularly in under-resourced schools or clinics, potentially creating disparities in early screening access. The variety of eye-tracking devices, each with different levels of precision, can result in variability in data quality, impacting diagnostic accuracy. Environmental factors, such as lighting, and participant-specific factors, like eye shape or corrective lenses, further complicate data reliability. Eye-tracking alone provides limited insights into non-visual cognitive aspects, such as auditory processing, highlighting the need for multimodal assessments.

Privacy and ethical considerations are also important, particularly when working with minors, as eye-tracking data involves sensitive gaze patterns. Additionally, an over-reliance on quantitative metrics risks oversimplifying dyslexia, potentially overlooking qualitative aspects like engagement or comprehension. Recognizing these limitations emphasizes the need for further research and refinement in eye-tracking methodologies to make them more inclusive, accessible, and ethically sound for dyslexia assessment.

4.14. Enriching Future Directions for Dyslexia Assessment Using Eye-Tracking

The future of dyslexia assessment through eye-tracking technology offers promising avenues for enhancing the diagnosis and treatment of dyslexia by leveraging personalized learning [61], multimodal approaches [62], and adaptive feedback [63]. A multifaceted diagnostic approach, combining eye-tracking data with other neurocognitive tools, can improve early identification and intervention strategies for dyslexic children.

Eye-tracking technology enables real-time, personalized feedback by identifying specific reading challenges, such as gaze distribution and fixation duration. This data can support tailored learning paths, where educators adjust reading materials based on each child's processing needs, fostering individualized, inclusive instruction.

Integrating eye-tracking with other methods, like EEG or pupillometry, provides a comprehensive evaluation of cognitive domains such as phonological processing, visual attention, and working memory. This holistic approach enables clinicians to design interventions that address the full spectrum of dyslexic challenges, from visual to cognitive deficits, in multimodal assessment approaches.

Eye-tracking insights allow for more effective practical interventions, such as adaptive learning tools that adjust reading tasks in real time or visual aids to reduce reading strain. In clinical settings, early screening informed by eye-tracking data can guide timely interventions, while adaptive feedback systems help track progress and adjust strategies based on concrete, measurable improvements. Extending eye-tracking research across linguistic and cultural backgrounds will further enable the development of adaptable, culturally responsive dyslexia assessment tools.

To conclude, the continued integration of eye-tracking technology with advanced neurocognitive assessments has the potential to transform dyslexia intervention strategies, promoting inclusive, evidence-based educational and clinical practices that meet diverse learning needs.

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